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Final Report

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MARTIAN SURFACE WEATHERING STUDIES

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SUMMARY

This work was designed to characterize the nature of the Martian surface by means of its reflectance properties. During the last year we tried to utilize the Mariner 9 photography to establish terrain units which were crossed by the Mariner 6 and 7 paths. The IR reflectance measured by the IR spectrometers on these spacecraft was to be used to indicate the nature of the surface within these units.

The answers obtained, as is often the case in IR work, are not unique. There is an indication of physical size and/or compositional variation between units but too many natural parameters can vary (size, shape, composition, adsorbed phases, reradiation, atmospheric absorption, temperature gradients, etc.) to be certain what effect is causing those variations observed. Hence, this report was not submitted for publication, although it may rest on as firm a foundation as others in this field.

It is suggested that the characterization could be fruitfully pursued by a group which was dedicated to peeling back the layers of minutia affecting IR reflectance. It does not seem to us that much more than chance import will emerge from interpretation of Martian surface IR spectra until this detailed approach is taken.

I. INTRODUCTION

The Mariner 6 and 7 spacecraft encountered the planet Mars on July 3 and August 5, 1969, respectively. On board the spacecraft were infrared spectrometers (IRS) which recorded spectra of the surface and atmosphere of the planet during these encounters. The details of the IRS are described separately (Herr, Forney and Pimentel, 1972). For this report it is sufficient to say that the infrared spectra covered the spectral range 1.9 to 14.4 microns on two channels. Only the shorter wavelength channel (1.9 to 6 microns) functioned properly on the Mariner 6 spacecraft.

The detection of a silicate absorption band in the 8 to 10 micron region has already been reported from the Mariner 6 and 7 data (Horn, et al., 1972) and from the Mariner 9 infrared interferometer (Hanel, et al., 1972a,b; Conrath, et al., 1973). This silicate absorption is ubiquitous over the non-polar cap areas of the planet and has been attributed to absorption by dust in the atmosphere (Herr, personal communication). A notable feature about this absorption is the lack of strong spectral contrast from one part of Mars to another.

There is temptation to interpret the composition of the Martian surface (or dust) directly from this ubiquitous silicate absorption following procedures outlined largely by Lyon (Lyon and Burns, 1963). Careful measurement of the band position indicates an intermediate silicate composition for Mars. It has been pointed out, however (Lyon, 1964; Van Tassel and Simon, 1964; Logan and Hunt, 1970), that many physical parameters, as well as chemical, control the position of *reststrahlung* or absorption bands in the infrared.

Experiments with the Mariner 6 and 7 backup spectrometer indicated that the spectra collected on Mars could be individually duplicated by varying grain size of different materials as well as by varying the composition of the materials themselves. The combination of emission from a complex surface, reabsorption and re-emission from layers of varying temperatures within the atmosphere holds little hope for the use of individual spectra (in the mid-infrared) as direct indicators of the composition of the Martian surface.

The Mariner 9 spacecraft orbited Mars, taking pictures of the planet through the Fall of 1971 and the Spring of 1972. A relatively complete synoptic coverage of the planet's surface was obtained by the spacecraft's television system during the extent of the mission. This coverage has been the basis of a generalized geologic map of Mars (Carr, et al., 1973). Preliminary geologic mapping on a smaller scale was accomplished both as a scientifically interesting study and as a tool for the forthcoming Viking Lander missions. During this preliminary mapping, several consistently differentiable map units were separated on the Martian surface by this author and by others. These units include bright plains, dark plains, hilly terrain, mountainous terrain, craters of differing degrees of freshness and relief, and chaotic and canyonlands terrain, the details of which are too small for illustration here. The tracks of the Mariner 6 and 7 spacecraft cross many different equatorial terrain features (cf. Carr, et al., supra).

II. INFRARED REFLECTANCE

Minnaert demonstrated (Minnaert, 1941) that the empirical reflective properties of a planetary surface could be related to the geometry of the observation by a relatively simple function if the planet followed the reciprocity principle. This function is $B \cos i = B_0 (\cos i \cos \epsilon)^k$.

B = the observed brightness of the planetary surface

i = the angle of incidence

ϵ = the angle of emergence

k = a dimensional parameter.

The function relates the observed brightness to the geometry of observation in such a way that at 0° incidence and emergence the observed brightness is equivalent to B_0 , the absolute brightness of the surface, and at either 90° emergence or 90° incidence the observed brightness is zero. If $B \cos \epsilon$ is plotted against $\cos \epsilon \cos i$ on log-log paper, the slope of the resulting plot will be the parameter k and the intercept at $\cos \epsilon \cos i = 1$ will be B_0 . In the visible part of the spectrum k is a fractional number generally lying between 0.5 and 1 (a Lambert surface). Its value appears to be related to the absolute reflectivity of the surface and to its roughness (Young and Collins, 1971).

Young and Collins quoted k values for the moon of 0.5 to 0.7 and gave k values for Mars that ranged between 0.46 and 0.48 for the center of Syrtis Major to 0.63 to 0.71 for the bright region Ophir. These values were computed at a phase angle of 22° . Young and Collins further stipulated that values of k between 0.5 and 0.7 were typical for dark particulate surfaces with negligible large-scale roughness, the lower values being associated with loose porous powders while the higher values are characteristic of more compact surfaces.

Veverka and Wasserman (1972) point out the effects of surface roughness on the interpretation of plots of Minnaert function. They point out that macroscopic roughness will alter the value of k either above or below its real value depending upon some of the geometrical parameters of the observation. They suggest a test for the azimuthal dependence of k to establish the reliability of this parameter in inferring the small-scale physical properties of the surface.

In the above mentioned report, the brightness data were collected in the visible portion of the spectrum. Since the IRS on Mariners 6 and 7 collected measured intensities over a large portion of the mid and near IR spectrum, we felt it would be instructive to plot infrared intensities by the Minnaert formula. In order to obtain background information for the applicability of this technique to infrared measurements, we used a helium-neon laser illuminating surfaces covered with natural materials of varying compositions and roughness. The results of such runs for basalt of different grain size and for andesine of different grain size are shown in Fig. 1. It should be noted that in only one of the runs, that on a coarse basalt ash (Lapilli sized grains) done at a phase angle of 50° , was the slope less than 0.8. These results may show an insensitivity of k to physical parameters (at large phase angles) or they may indicate a narrow range in the physical properties of the materials considered. Other materials were examined briefly with undistinguished results.

III. MARS REFLECTANCE

The measured infrared intensities of Mars at different wavelengths are plotted in Figs. 2 and 3. The groupings of points plotted were selected from preliminary geologic mapping done for the Viking Site Selection task. It is readily apparent that there is a large variation in the

absolute brightness of the different areas at the same wavelength but that not much difference and little or no consistent variation is seen for the value of k between such units. The values of the brightness were plotted independently for different phase angles but in most cases the plots for the same unit lie on or near the same straight line approximation for all the phase angles observed. After plotting, the azimuth of each measurement was determined by the formula given in Veverka and Wasserman (1972):

$\cos A = \frac{(\cos \alpha - \cos i \cos \epsilon)}{(\sin i \sin \epsilon)}$. The variation in azimuth has little or no effect on the calculation of k from the Martian infrared data.

The variation of reflectance along with constancy of k can have two interpretations. One, the material of the Martian surface is remarkably consistent in its physical properties (i.e., grain size and distribution of grain size, packing and soil density). Two, this technique is insensitive to the range of variation of physical properties of the Martian surface. The second alternative is not considered as likely as the first since our laboratory experiments were able to detect a variation in coarseness between samples with a predictable natural range of physical properties. It can be effectively argued that the range of variation could be smaller than that used in our laboratory samples. However, this argument converges with the first alternative, that is, there is little or no variation in physical properties between units mapped differently on the Mariner 9 photography and showing different infrared reflectivities on Mariners 6 and 7.

If the grain size and packing of dark and light areas are similar and if large scale roughness does not account for variations in visible and infrared reflectivity, we may alternatively postulate compositional variation to account for the brightness range we see on the Martian surface.

As was noted above, compositional variation at first glance appears ruled out by the consistency of the infrared spectra in the 8-10 micron band. This apparent conflict of data may not be overwhelming, however, for two reasons. (1) Most of the absorption for this 8-10 micron band may come from dust suspended in the atmosphere. The grain size of this dust may be quite small and somewhat variable and the temperature range of the absorbing particles may be great. If the variations are sufficient and the grain size small enough, a ubiquitous silicate absorption centered at some indeterminate point could result and this could be the silicate band which we see. (2) The composition of silicates as noted by position of absorption bands, particularly in the 8-10 micron region, is often a tenuous identification of silicon, little more than a sophisticated color index. It is, in fact, difficult to distinguish between many minerals of the same suite (such as the minerals comprising a basalt) although it is often easy to differentiate minerals of different suites, for example, quartz or alkali feldspar from granitic rocks versus pyroxenes or calcic plagioclases from basalts. If the mineralogy of the Martian surface is similar to that of the lunar surface, i.e., basaltic, recognition of minerals of the basalt suite physically separated from one another could be a difficult task by means of remote infrared spectroscopy. If the light areas of Mars are comprised predominantly of calcic feldspar resulting either from igneous or post-eruption concentration processes and the dark areas are comprised of undifferentiated basaltic materials, the infrared spectra of these two areas could be quite similar.

The process of magmatic differentiation is well documented from lunar samples as well as terrestrial. The process of air-elutriation of the light minerals from the dark in a dry, weak planetary atmosphere is a speculative

possibility to aid such differentiation. Elutriation does have the added advantage of being the type of process which could lead to the formation of dust clouds of substantially the same optical characteristics as the light areas of Mars. It also has the advantage of being a process which could be directly responsible for producing iron oxides and thus the ubiquitous orangeish color of the planet.

With the discovery of ancient stream channels, indicating the presence (at least in antiquity) of water on Mars, there is perhaps not as much need for speculating on an oxidizing process as was once believed. The suggestion that the difference between dark and light areas on Mars can be explained by a compositional difference within a suite of basaltic minerals is not meant to denigrate the rich geologic history of that planet. It is also not new as any student of Mars will realize (Adams, 1968). It is merely meant to offer a simple hypothesis consistent with the data presently known about the Martian surface.

IV. CONCLUSIONS

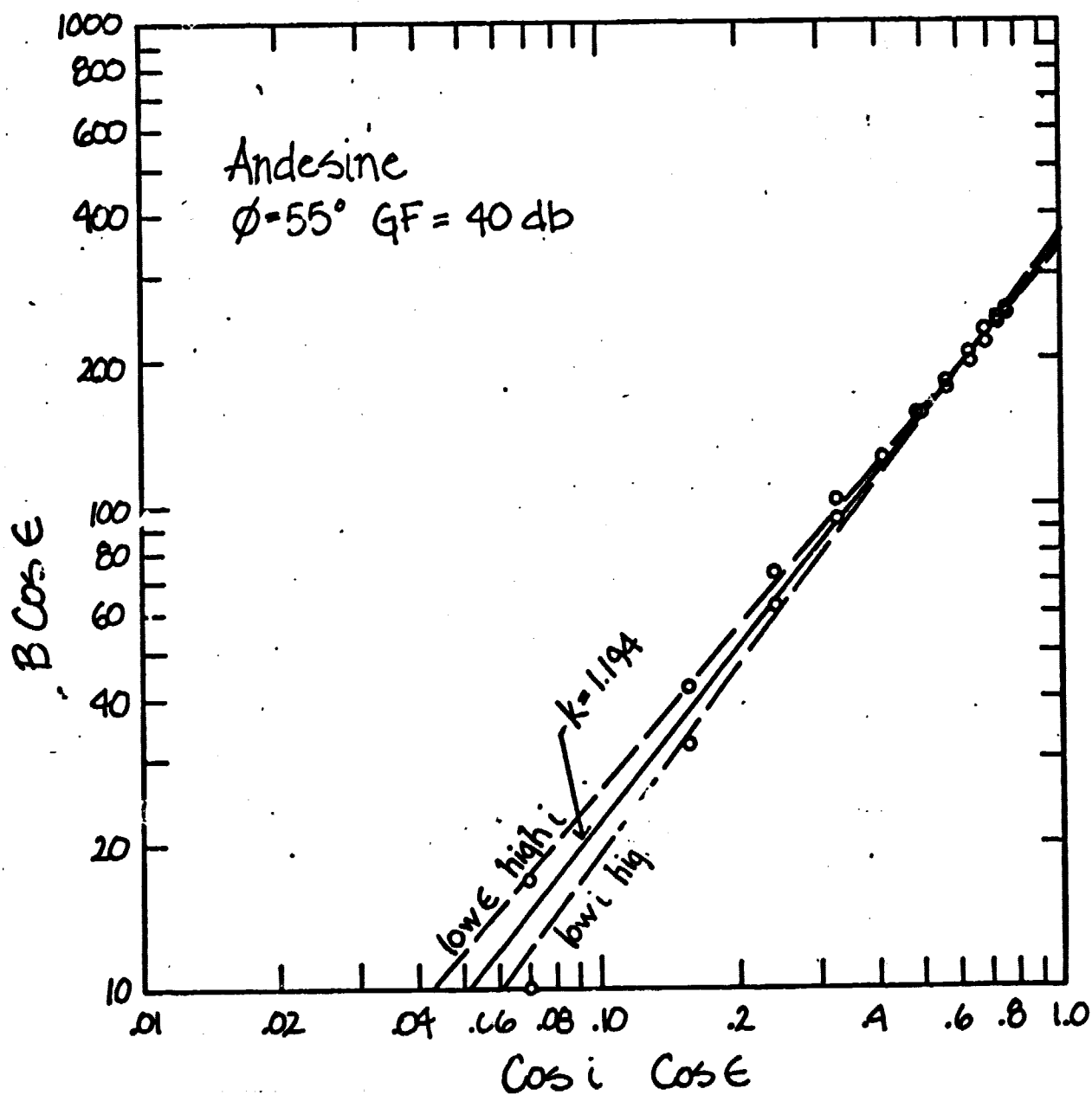
Minnaert plots of infrared reflectance at various wavelengths indicate that the materials comprising the Martian surface are fairly uniform in their physical properties, at least over Mariner 6 and 7 tracks. Laboratory experiments with infrared reflectance indicate that moderate to large variations in grain size and/or packing would be shown up by Minnaert plots of IR reflectance. Interpretation of the differences in reflectance in the visible and the infrared are not inconsistent with the development of compositional differences between the light and the dark areas on Mars. The light areas could consist predominantly of feldspars (calcium plagioclase) emplaced either by magmatic or post-depositional processes (weathering and

elutriation) while the dark areas are basaltic and essentially undifferentiated. Infrared absorption bands in the 8-10 micron region from Mariners 6, 7 and 9 are not inconsistent with this interpretation of the Martian surface composition if attention is paid to grain size, absorption, and re-emission effects at various temperatures.

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